Limitations of Science and Adaptive Management

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Abstract

Adaptive management consists in patterning human sustenance within the constraints of Earth and biological systems whose behavior is inherently uncertain and difficult to control. For successful adaptive management, a mind-set recognizing the limitations of science is needed.

Limitations of Science and Adaptive Management

Science and its Limitations

Modern science has identified laws governing the inanimate universe. Using these, it endeavors to precisely describe the world around us with numbers, and to predict and control the behavior of Earth systems for human benefit. Nevertheless, the credibility of this desire to predict and control is becoming questionable as knowledge of Earth's environmental and biological systems accumulate. Although geological processes are comprehended within the framework of mechanics and thermodynamics, precise quantification of Earth systems is exceptionally difficult, or even impossible, owing to difficulties of access and observation, sparsity of data, multiplicity of spatial and temporal scales, heterogeneity, coupling among diverse processes, feed-back among system components, and unknown forcing functions such as climate.

The Earth's biological systems pose a different challenge. Though much is known about the materials constituting the physical make up of living things, the non-material phenomenon of life itself has not been brought within science's logical framework. Living things possess mind (or, instinct), an attribute not possessed by inanimate objects. They have a will to survive, and the ability to adapt for survival. Survival, in turn, may involve a single individual, or a collection of individuals. While the instinct for survival of an individual may be rationalized in terms of a discriminating mind, the question of how a whole species may sense its surroundings, evaluate consequences, and initiate suitable physical and chemical changes in the bodies of individual organisms for survival eludes comprehension. Darwin's theory of evolution is observationally established, but science knows little about life's abstract attributes that underlie evolution.

In the case of humans, qualities such as emotion, spirituality, aesthetics, morality, and values further complicate quantified understanding. These qualities are characterized by pairs of opposites such as love and hate, compassion and violence, greed and generosity, and rationality and irrationality. Invariably, human behavior depends on the relative magnitudes of these pairs of opposite that may coexist in a given situation. Consequently, human decision-making is subject to inherent unpredictability, transcending fixed laws. In contrast, inanimate systems conform to physical laws that have presumably remained immutable for billions of years. The adage, "the present is the key to the past", may apply to geological processes, but cannot be applied to human behavior. Laws governing human societies are transient[1].

Earth and biological sciences are interpretive and historical.[2] They can explain observed patterns with varying levels of quantitative detail. Extrapolating knowledge of the past to the future, however, is beset with uncertainty and imprecision[3]. Mathematical models and computational tools are of practical use in providing insights about possible system responses over the near-future, rather than precisely predicting system behavior. It has been pointed out that the primary value of models is heuristic.[4]

Despite clear evidence of the limitations of science concerning Earth and its biological systems, contemporary scientific research is largely driven by aspirations of prediction and control. For example, research is vigorously pursued to eradicate major diseases, or to prolong human life indefinitely through genetic engineering, novel materials, or nanotechnology. Scant consideration is given to the possibility that the material and psychological consequences of simultaneously supporting several generations of population can be as devastating as that of population explosion. Nor is attention given to the possibility that as science succeeds in controlling some diseases, nature may respond with more virulent new maladies.

Adapting to Natural Systems

How may humans sustain on a finite earth in which behavioral patterns of life-sustaining resource systems can be understood, but cannot be predicted? Reason suggests that society must adapt its functioning to the constraints imposed by the nature of these resource systems. Intrinsic to this adaptive management mind-set is timely recognition of unintended consequences of human actions,

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[1] Narasimhan, T.N (2003)., *A finite world, earth sciences, and public trust,* Groun Water, 41 (1), 11-14

[2] Frodeman, R (1995), *Geological reasoning: Geology as interpretive historical science*,Bull. Geol. Soc. Am., 107 (8), 960-968

[3] Scriven, M. (1959), *Explanation and prediction in evolutionary theory,* Science, 130, 477-482

[4] Oreskes, N., Shrader-Frechette, K., Belitz, K (1994), *Verification, validation, and conformation of numerical models in the Earth sciences*, Science, 263, 641-646

and initiation of changes in resource use patterns to avert deleterious responses of the systems involved.

The concept of adaptive management is not as widely accepted as one might rationally imagine. Impelled by aspirations of economic growth, rich and poor nations alike pursue policies of rapid resource depletion, environmental degradation, and endangerment of ecosystems. Legislators and policy makers who are eager to reap the benefits of science for economic growth are less comfortable in heeding what the same science has to say about the imperative for adapting to a finite Earth.

Adaptive management consists in patterning human sustenance within the constraints of Earth and biological systems whose behavior is inherently uncertain and difficult to control. To compensate for these, resource management science has devised three approaches: quantifying uncertainty, risk management, and monitoring of resource systems.

Quantification of uncertainty is largely based on probability theory, and the associated statistics of random variables Estimates of probability, credible in case of mutually independent discrete events, become progressively less so when the outcome of interest depends on an increasing number mutually influencing events, leading to conditional probability. Such mutual influence of a large number of poorly known causes is the rule in the case of natural disasters such as earthquakes, hurricanes, droughts, or pandemics. Therefore, probabilistic estimates of the behavior of complex natural systems are of qualitative value at best under favorable circumstances..

Risk management is based on the premise that potential benefits or losses of human ventures can be quantified in terms of a common denominator such as money, and that the relative costs involved constitute a reliable measure to guide decision-making. Risk management may be of value in narrowly defined ventures in which costs and benefits can be numerically quantified with some credibility. But, as the scope of a venture broadens to include an increasing number of components of Earth and biological systems, risk management too will only be of qualitative value under favorable circumstances. Money is perhaps the most widely used common denominator in risk management. Yet, variations in the value of money from one component of society to another are so variable and transient that money cannot credibly serve as a common denominator when many segments of society are involved or when a venture cuts across national borders.

The rationale for monitoring is that it will (a) provide data for progressively adjusting the parameters of mathematical models, and (b) provide early warning of unforeseen consequences of human action so as to initiate timely corrective measures. Nevertheless, the concept of monitoring is often not looked on favorably by those who develop and exploit natural resources. An innate concern is that monitoring might reveal information that may negatively impact resource use. Also, systematic monitoring essential for adaptive management can be expensive. For these reasons, monitoring as a necessary adjunct for adaptive management is a concept in its infancy. Much remains to be done about technical issues associated with monitoring such as scope of monitoring, instrumentation, data acquisition systems, data storage, interpretation, retrieval and dissemination, as well as legislative, institutional and financial aspects.

Role of Science

The arguments presented above on the limitations of science in comprehending Earth and biological systems do not negate the importance of science. Rather, they call for an examination of the role of science in adaptive management.

During the nineteenth century, Maxwell[5] and Lord Kelvin[6] saw quantification as being so essential as to believe that there was no science without numbers. This perception gained strength subsequently with explosive developments in the physical sciences. However, from what we now know about the nature of the Earth's hydrological, nutrient, and erosional cycles, we can reasonably question the tenet that science is synonymous with numbers, and that there is no science without precise quantification. For reasons already enumerated, there are aspects of Earth and biological systems of vital importance to society that are not amenable to precise quantification, but only permit comparison through approximate, relative magnitudes.[7] Thus, adaptive management encompasses problems ranging from those that can be resolved by precise, quantitative methods to those that have to be addressed through non-quantitative descriptive thought. In the continuum of human

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[5] Maxwell, J. C. (1864), *Faraday's lines of force,* Trans. Cambridge Phil. Soc., Vol. X, Pt. 1, p. 27

[6] Thomson, W., 1891, *Electrical units of measurement*, in Nature Series, Popular Lectures and addresses; McmIllan and Co, London and New York, v. 1, Constitution of Matter, 80-134

[7] Hubbert, M.K. (1974), *Is being quantitative sufficient?*, in The impact of quantification on geology, Proceedings of the First Geochautauqua , Syracuse University, October, 1972, Editor D.F. Merriam, Syracuse University Geology Contribution No. 2

knowledge, science lies at one end, devoted to deciphering rational patterns in the observable world. At the other lie the humanities, concerned with the abstract world of emotion, esthetics, spirituality, morality, and philosophy. The functioning of human societies is governed by all shades of knowledge between these extremes.

An Example

One example of adaptation to unintended consequences of human action merits attention. The San Joaquin Valley of California, a narrow intermontane basin lying in an arid region, has been transformed into one of the richest agricultural regions of the world through irrigation with water imported from outside the basin. For nearly a century, the only obstacle challenging irrigation technology was progressive, irreversible soil salinization caused by salt brought in with the imported water. The salinization problem had been kept temporarily in check by capturing salt-laden waters below the root zone with subsurface drains, and conveying the return flows to a distant, constructed wet land, the Kesterson Wild Life Refuge. Even as science was exploring more permanent technological solutions for the salinity problem, it was taken by surprise in 1983 by the discovery of selenium poisoning of wild fowl at Kesterson. It was found that selenium, a redox sensitive metal, is present in the solid state in the sediments of valley flanks that had originally formed under reducing (oxygen-deficient) conditions. When, oxygen-rich imported irrigation waters were applied over these sediments, selenium was oxidized, became water-soluble, and found its way via the 90-mile long San Luis Drain to the Kesterson wetlands, endangering wildlife. Although the chemistry of soils and water of this area had been intensively studied by agricultural scientists from the late 19th century, the potential for selenium toxicity was never suspected.

The impact of irrigated agriculture on wild life had an immediate profound effect on public perceptions about the importance of the Valley's agriculture. For the first time, environmental health was perceived to be more important, demanding higher priority than economic benefits. After vigorous public debate, the Valley adapted immediately to selenium toxicity by prohibiting discharge of drainage effluents into the San Luis Drain. Over the past two decades, the farmers of western San Joaquin Valley, the U.S. Bureau of Reclamation, and environmental groups have been involved in litigation and actively debating ways of more permanently adapting to problems stemming from salinization and selenium toxicity. At present, two alternatives are under consideration. The technological option is to convey irrigation effluents via a pipeline to the Pacific Ocean over the Coast Range, or down the valley to the San Francisco Bay. The environmental option is for the federal government to buy back 300,000 acres of land, and retire them permanently from irrigated agriculture.[8] In addition to substantial costs, the technological option is constrained by potential negative impacts on marine or estuarine ecosystems. The environmental option is constrained by farmers having to give up their lands. This case history gives a glimpse into the complexity of technical-human issues of adaptive management.

Change of Mind-set

Clearly, adaptive management requires changes in the mind-set of scientists as well as of legislators and policy makers. In the aftermath of the Second World war, spectacular developments in the physical sciences, and the ascent of democracy the world over have nourished human aspirations of material prosperity, good health and longevity for all segments of society. Responding to these aspirations, nations around the world are seeking significant and continued economic growth, assuming that science and technology will predict and control the behavior of Earth and biological systems to fuel the growth. Unfortunately, such expectations will be jeopardized by collateral damages to the environment and ecosystems, in addition to degradation of the resource base itself. Given this, adaptive management demands a moderation of human aspirations compatible with the nature of the Earth's renewable and non-renewable resource systems vital for human sustenance.

Curiosity is a gift that drives science. The human mind must have the freedom to pursue any question about the world around us that it deems reasonable to pursue. But, our contemporary funding atmosphere for scientific research is such that the lines between pursuing curiosity on the hand, and providing direct benefit to society on the other, are blurred. Emerging questions about science and ethics have their roots in striking a balance between the right to pursue curiosity and the need to conform to the constraints within which humans have to sustain existence on a finite Earth.

Conclusion

What may lie ahead for adaptive management? Although the concept makes rational sense, having the will to implement it is fraught with difficulties stemming from human nature. The desire to comprehend the world around us precisely so as to control it for our benefit is a vision that dates four

[8] U. S. Bureau of Reclamation, http://www.usbr.gov/mp/sccao/sld/overview.html

centuries back to Francis Bacon[9]. Modern science cannot easily give up this vision. Secondly, adaptive management requires a combination of quantitative thinking as well as non-quantitative, descriptive logic. For this to happen, science and the humanities (with the social sciences in between) have to come together in unprecedented ways.

To put things in perspective, consider a hypothetical case. Suppose, due to global warming, gradual rise in sea level progressively inundates highly populated areas of the Texas Gulf Coast or Bangladesh. How will science and society respond? Will technology-based policy advocate building dykes and barriers to protect local populations? Or, will large sections of population be relocated within or across national boundaries? How will policy respond when one section of population asserts its rights to safety at a cost that is prohibitive to society as a whole? How may large, displaced populations be accommodated within or outside of national boundaries? It is impossible to foresee what the outcomes might be. The possibility of violent conflicts cannot be ruled out. However, it is clear that major decisions can neither be based purely on technology, nor based purely on social values. Civilized adaptation will require a balancing of the quantitative and the descriptive, and an ability to make judgements under trying conditions. In order that these judgements may be wise, we have a long way to travel in closing the gap between the sciences and the humanities, between quantitative thinking and descriptive thinking.

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[9] Broad, C. B. (1959), *Bacon and the experimental method,* in A short history of science, A Symposium, Doubleday Anchor Books, New York, 27-33